# See-through AR Display Based on Waveguide Combiner withSurface Relief Grating

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**ABSRTACT**

*In this research, the diffractive waveguide elementscan treat as reflection or transmission elements depending on different observation directions. The devicecan achieve one dimension exit pupil expansion, and approximate a horizonal FOV of 34 deg in reflection element and transmission element respectively.*

## 1 Introduction

Augmented Reality (AR) is the technology combines virtual information and real environment. It is often combined with Head Mounted Display (HMD) to transmit the required information to the human eyes. However, the traditional see-through HMD system made of geometric optical elements has a large volume and heavy weight. In recent years, it is common to use holographic optical elements (HOEs)to replace traditional optical elements.

Among the HOE, thin gratings have advantage in producing user large field of view (FOV) display because of its low wavelength selectivity and low angular selectivity, the aberration can be compensatedby symmetrical grating structure.

In this research, thin grating is used in order to build up holographic waveguide elements by holographical technology. The manufacture process is with spin coating of the photoresist on glass substrate, and then the photoresist will record the LASER interference fringes and will be developed to produce grating. The photoresist is AR–P7400, and the developer is AR 300–26.

In our diffractive waveguide element (DWE), it canbe used in both reflective and transmission mode depending on different observation direction shown as Fig. 1. The projective information is normal incidentinto in-coupling grating and then is with total internal reflection in waveguide. Then, the information will be coupled out by the out-coupling grating and will be diffracted with +1 and -1 order. The reflective mode is observed with +1 order of diffraction and the transmission mode is observed with -1 order of diffraction. The device is expected to provide a large FOV for green LED lighting.

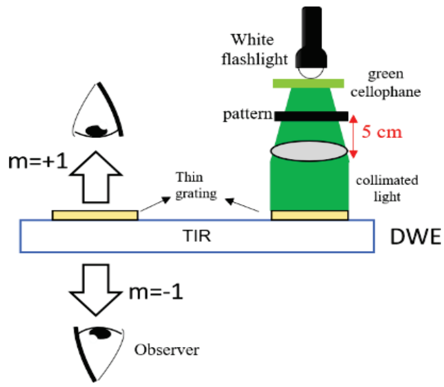



**Fig. 1 The schematic diagram of AR display device compose a pair of thin grating.**

## 2 Experiment

The parameters of recording grating are determined by simulation in MATLAB base on Eq.1

$$d(n_2 \sin\varphi \pm n_1 \sin\theta) = m\lambda \; \dots\dots (1)$$

Where $\theta$ is the angle of incidence, $\varphi$ is the angle of diffraction, $m$ is the order of diffracted light, $d$ is the grating period, $\lambda$ is the wavelength of incident light, $n_1$ is the refractive index of the incident medium, and $n_2$ is the refractive index of the diffractive medium.

In this experiment, the LASER wavelength is 457 *nm* and it is used to produce interference fringes It is expected to choose a propriate grating period that the 532 *nm* light normal incident to grating will be diffracted at $55°$ of diffractive angle which satisfy the condition of total internal reflection (TIR) in waveguide.

To reduce the inclination angle of grating, the angle of two incident light must be symmetry. Finally, we use $-31.84°$ and $31.84°$ for recoding, as shown in Fig. 2, which provide a grating period 433.19 *nm.*

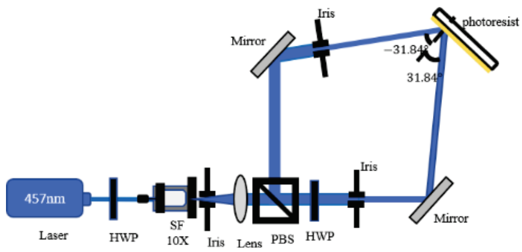



**Fig. 2 The recorded system of DWE. HWP: half-wave plate; PBS: polarized beam splitter; SF: spatial filter**

The interference area is a circle with a diameter of 2 cm, the in-coupling grating and out-coupling grating are recorded on the same side of the waveguide to form the symmetrical grating structure.

To calculate the angle of diffraction, the refractive index of glass in 532*nm* light is necessary. The refractive index of glass and critical angle can be calculated by Eq. 2 and Brewster's angle can be measured by using TM mode light.

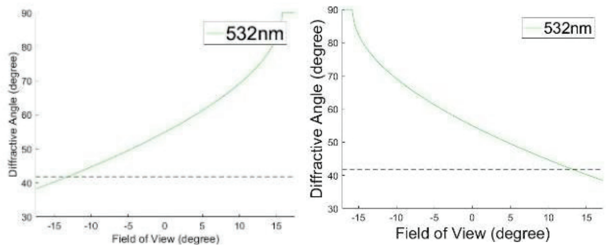
$$\boldsymbol{\theta_B = \tan^{-1}\frac{n_{glass}}{1}\ ,\theta_C = \sin^{-1}\frac{1}{n_{glass}}} \ldots \textbf{(2)}$$

**Table. 1 The refractive index and critical angle ofglass in 532 *nm* wavelength light**

| *wavelength* | $n_{glass}$ | $\theta_C$ |
|---|---|---|
| *532 nm* | 1.520 | 41.12° |

Where $\theta_B$ is Brewster's angle, $\theta_c$ is critical angle and $n_{glass}$ refractive index.

The FOV of image is simulated by MATLAB which is shown as Fig. 3, where the vertical axis is diffractive angle of light in waveguide, and the horizontal axis is the FOV, the dotted line is the critical angle.



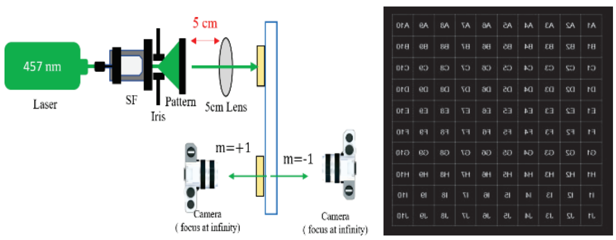

**(a) (b)**

**Fig. 3 The relation between diffractive angle and FOVwith 532 *nm* wavelength backlight by (a) +1 order of diffraction (b) -1 order of diffraction**

## 3 Result

### 3.1 LASER Backlight

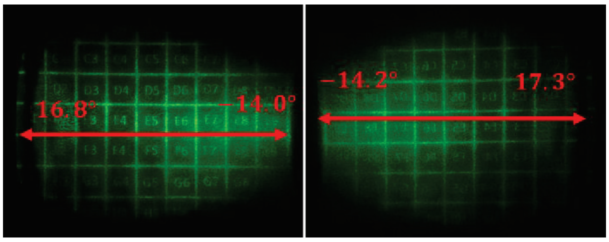
Taking LASER as lighting for the source to generate an information image locating at infinity. The pattern information is coupled into the waveguide by the in-coupling HOE and will be coupled out to camera which focused at infinity. The pattern is with $10 \times 10$ grid and the size of each grid is 3 *mm* by 3 *mm*. The focal length of camera is 5 *cm* and the observation system is shown as Fig. 4.




**(a) (b)**

**Fig.4 The observation with LASER backlight by (a) the experimental setup with (b) the target pattern**

Fig. 5 shows the experimental results with LASER wavelength of 532 *nm*. It is expected that the DWE will provides a FOV of $-13.2°\sim15.8°$ both in +1 and -1order diffraction and it provides a horizonal FOV of $-13.1°\sim13.9°$and $-13.0°\sim13.6°$ experimentally. It can be found from that experiment matched to our simulation.



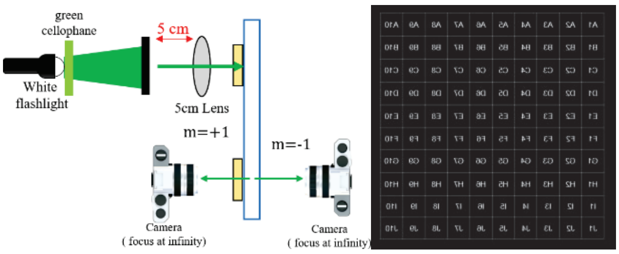

(a) (b)

**Fig. 5 The FOV of image with 532 *nm* LASER backlight in (a) +1 order direction observation (b) -1 order direction observation.**

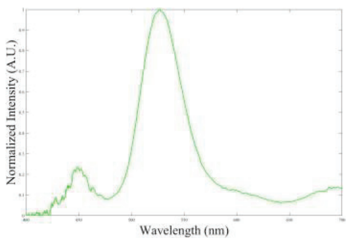
Comparing the +1 order diffraction with the -1 order diffraction, the image of +1 order is clearer than -1 order. Optimized -1 order diffraction can be obtained. This is our future work.

### 3.2 LED Backlight

After confirming our simulation is correct, we use LED with green as backlight to show the result in common light source condition as shown in Fig. 6. The LED backlight will provide a larger FOV than the LASER light because of the wider spectrum of LED.



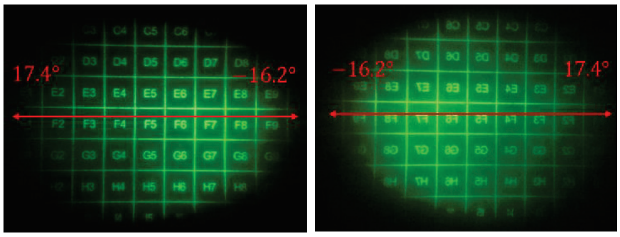

(a) (b)




(c)

**Fig. 6 The observation with LED backlight by (a) the experimental setup (b) the target pattern (c) the spectrum of LED with green cellophane**

In LED backlight condition, the DWE provides a FOV of $-17.2°\sim16.5°$ and $-15.3°\sim14.1°$ in +1 and -1 order observation respectively.




(a) (b)

**Fig. 7 The FOV of image with green cellophane LED backlight in (a) +1 order direction (b) -1 order direction observation.**

## 4 Discussion

In this experiment, it is confirmed that the waveguidecan be operated in reflection mode and transmission mode. The image is more vague at the positive FOV position than that at the negative FOV position. The reason maybe is the manufacturing process problem which leads to lower uniformity for the overall grating. To solve the uniformity problem, we can use higher magnification of spatial filter to increase the exposure uniformity or use the hologram embossing method to replace the exposure and development process.

## 5 Conclusion

In this paper, DWE is successfully generated with recording of interference pattern on photoresist layer. The DWE is designed for green light condition and thin grating is used because of the low angular selectivity and low wavelength selectivity can achieve a largeFOV. Finally, with LED as backlight, the DWE canprovide approximate $34°$ of horizontal FOV and $21°$ of vertical FOV in +1 and -1 order of diffraction. The aberration of this device is compensated by the symmetrical grating structure.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## Reference

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